Engineering Sciences
Plasma modeling

Zap, Crackle, Pop! Simulating Arc Discharges

New codes will reveal the details for electrical arc initiation and evolution

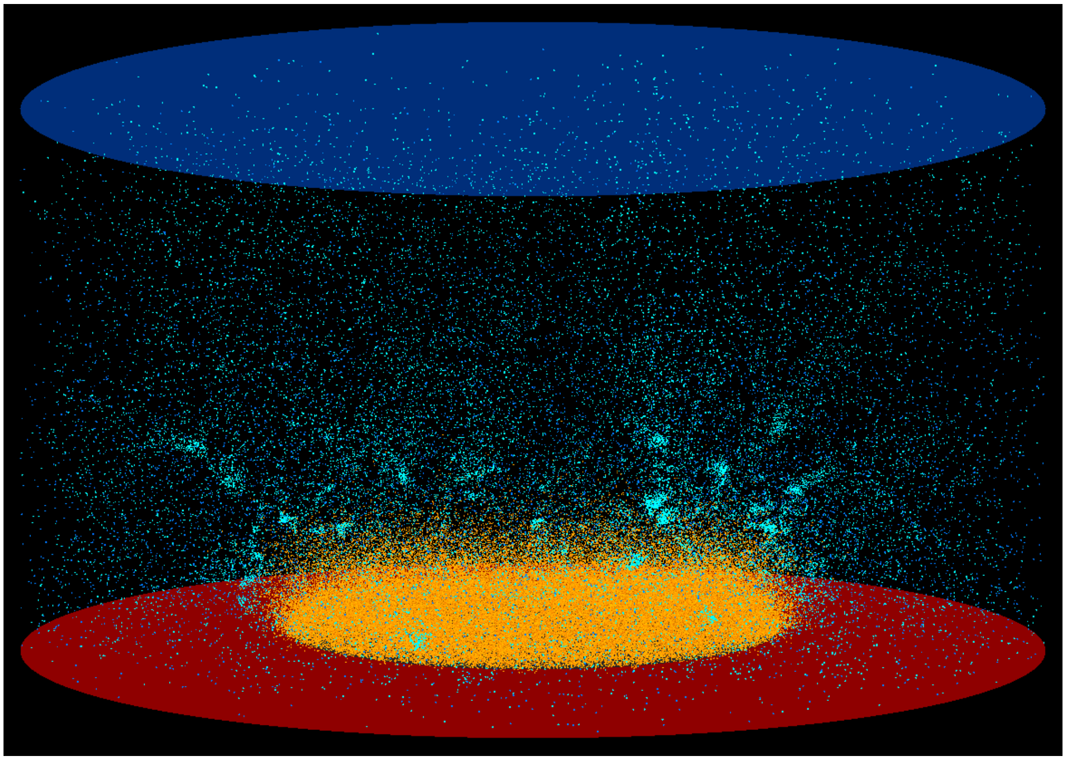

Figure 1: Electrons (blue) from a "virtual" cathode at top have heated the bottom anode, generating a tremendous number of neutral titanium atoms (orange). Some of these in turn have been ionized by electrons, producing titanium ions (light blue). Note the localized multiple ionization events.

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Arc discharges are encountered all the time, every day. Spark plugs in a car, static discharge with a doorknob, fluorescent lighting, and atmospheric lightning all operate according to similar principles. Yet there is no predictive model for their initiation and evolution suitable for the advanced design and engineering tasks performed at Sandia (with increasing frequency). Thus over the past two years, there have been efforts to develop new models within the Aleph low temperature non-continuum plasma simulation tool to help understand arc discharge initiation and evolution. Although the primary motivation is to understand plasma arc discharges in neutron tubes, these models apply to other discharge events, including other arc-based devices.

An arc discharge in an electrode-based system begins with electrons traveling from a cathode to an anode due to a voltage drop across the gap. The incoming electrons heat up the anode; when it gets very hot, the anode releases neutral atoms (see Figure 1). As it gets hotter and hotter, more and more neutral atoms are released from the anode. Occasionally, an electron and neutral atom collide or interact strongly enough to ionize the atom by knocking off one of its outer electrons. Thus, one electron and one neutral atom are converted into two electrons and one ion. If the conditions are just right, those two electrons now have the opportunity to ionize more neutral atoms, etc., leading to a very rapid increase in ionization rate called an "electron avalanche" or a "cascade event."

In other words, an "arc" is formed. The arc persists as long as the drive conditions and source materials are available. In this simplified description, many details are omitted that are necessary to realistically model how arcs form. Much of Sandia's research effort is spent digging through those details, constructing models based on them, and testing them within the Aleph code.

A simulation exhibiting some of these events as a function of time is shown in Figure 2. Only a small fraction of the actual particles in the simulation are displayed. The lower surface contains the anode (center disc). However, unlike the above description, we do not have an actual cathode in the simulation. The upper surface is simply emitting a constant stream of electrons, acting as a "virtual" cathode. The electrons travel to the anode, where their energy is deposited and heats the material. The temperature is tracked, and a desorption (vaporization) model is used to emit neutral titanium atoms. Those atoms diffuse away from the surface, and occasionally one is ionized by an incoming electron, producing titanium ions. Cascade-like events can clearly be seen.

A fully developed predictive arc simulation tool will improve our scientific understanding of the initial plasma breakdown event. In addition to pure scientific understanding, a predictive tool will also allow us to perform device optimization and uncertainty quantification. These advanced design and engineering processes lead to reduced costs, shorter design and analysis cycles, and overall higher quality and confidence in product performance. We have made great progress in the first two years, but still have much to discover and learn.

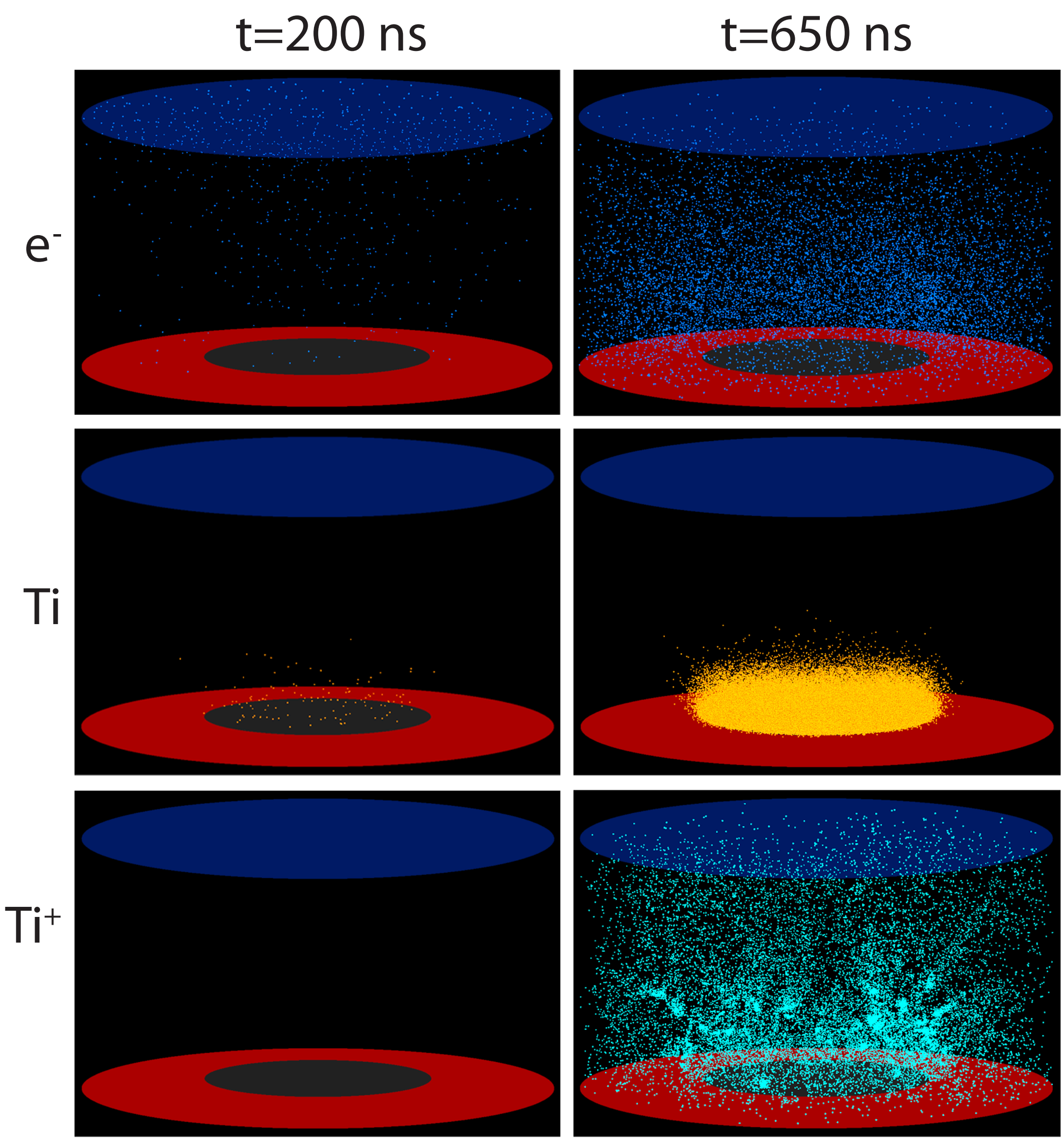

Figure 2: Evolution of arc initiation over time. At 200 nsec, the anode has been heated only slightly, emitting some neutral titanium atoms. At 650 nsec the greatly increased heating of the anode leads to the generation of many more neutral titanium atoms, and thus a much higher ionization rate. Note in particular some cascade-like ionization events.

Sandia National Laboratories

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